WSRC-TR-2001-00289
Revision 0

Assay of 321-M Process Pressure Cookers for HEU Holdup by Far Field gPHA and by the Adapted Q^2 Technique

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Keywords:
Deactivation, NDA, Multichannel,
Transmission, Segmented, Holdup

Classification: U

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Authorized Derivative Classifier

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Publication Date: August 31, 2001

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This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U.S. Department of Energy.

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ABSTRACT

The Analytical Development Section of Savannah River Technology Center (SRTC) was requested by the Facilities Disposition Division (FDD) to determine the holdup of enriched uranium in the 321-M facility as part of an overall deactivation project of the facility. The 321-M facility was used to fabricate highly enriched uranium (HEU) fuel assemblies, lithium-aluminum target tubes, neptunium assemblies, and miscellaneous components for the production reactors. The facility also includes the 324-M storage building and the passageway connecting it to 321-M. The results of the holdup assays are essential for determining compliance with the Waste Acceptance Criteria, Material Control & Accountability, and to meet criticality safety controls. This report discusses the methodology, measurements, assumptions, and results of the ^{235}U holdup content determinations for 108 process pressure cookers. Twelve pressure cookers were assayed with a far field γ-PHA assay system, and all 108 were assayed using the Canberra Q^2 adapted to use as a three-segment segmented γ-scanner. The report includes a comparison of the results obtained by the two methods. Our results show that the pressure cookers contained quantities of ^{235}U ranging from 0.07 to 0.19 grams and for 55 gal drums containing nine pressure cookers using our batch technique of assay, we reported HEU residue contents ranging from 0.50±0.07 to 0.87±0.26 grams per drum.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Assay of 321-M Process Pressure Cookers for HEU Holdup by Far Field gPHA and by the Adapted Q^2 Technique

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1. INTRODUCTION

The 321-M facility was used to fabricate highly enriched uranium (HEU) fuel assemblies, lithium-aluminum target tubes, neptunium assemblies, and miscellaneous components for the production reactors. The facility also includes the 324-M storage building and the passageway connecting it to 321-M. The facility operated for 25 years. During this time thousands of uranium-aluminum-alloy (U-Al) fuel tubes were produced. After the facility ceased operations in 1995, all of the easily accessible U-Al was removed from the building, and only residual amounts remained. The bulk of this residue is located in the equipment that generated and handled small U-Al particles and the exhaust systems for this equipment (e.g., Chip compactor, casting furnaces, log saw, lathes A & B, cyclone separator, Freonä cart, riser crusher, …etc). [1]

As each piece of process equipment is decontaminated in the deactivation project, HEU residue has been collected into 2-gallon scrap cans for nondestructive γ-PHA assay (NDA) using the 324-M far field transmission corrected assay station, which has been described previously in references 2 and 3. One of the specific uses of the assay station is to assay for ^{235}U content in scrap cans, and with it we have demonstrated a capability to determine ^{235}U content in the range of 0.1 g up to 26 g. With a 600-second acquisition, we have demonstrated a lower limit of detection of 0.1 g ^{235}U using two techniques of calculation of content from the measured γ-ray data.[4]

This report describes use of the assay station to perform holdup determinations in twelve pressure cookers. The pressure cookers are process equipment used in the 321-M facility for production of U-Al reactor fuel and target elements. Each pressure cooker has been emptied of process material but is expected to contain measurable HEU residue and contamination. The individual assays are required to monitor for criticality concerns during the deactivation of the 321-M facility and to satisfy material control & accountability concerns and waste acceptance criteria.[1,5,6] Since the pressure cookers have size and shape very similar to the 2-gallon scrap cans, the individual assay station assembled to assay them is especially suited to assay the pressure cookers also.

Also in this report we describe data acquisition and calculations to assay 108 pressure cookers using the adapted Q^2 technique. This adapted technique allowed batch assay of the pressure cookers in groups of nine at a time. The technique was developed by two SRTC scientists for assay of high-density solid waste and for batch assay of empty 321-M scrap cans.[7,8] Comparison of the data acquired using the batch assay technique to the data and results of the individual far field assays are discussed.

2. EXPERIMENTAL

2.1 Far Field gPHA Acquisitions

Using the far field γ-PHA assay station as described in reference 2, we have assayed approximately 100 scrap cans that contained waste material and residue from the Facilities Disposition Division (FDD) deactivation of Building 321-M. Also using that assay station, we have assayed 268 uranium storage pigs as described in reference 9. Each of the storage pigs was known previously to be empty of material and to contain, if anything, ^{235}U residue only. The pigs were all assayed and reported to contain less than the lower limit of detection (LLD) of 0.2 g ^{235}U. The limit of detection for the scrap cans was determined to be 0.1 g ^{235}U, and measured values up to 27 grams HEU were reported.[4]

The 321-M process pressure cookers are very similar in size and shape to the scrap cans. Since the pressure cookers are made of aluminum with wall thickness of only several millimeters, the transmission characteristics for the 185-KeV γ-ray should be even more favorable (ie. less absorbing) than those of the scrap cans which are made of steel. It was determined that the pressure cookers could be assayed using the far field assay station assembled for the scrap cans.

The cookers contained process material residue only – no process material was present in any quantity sufficient to contribute significantly to the sample self-absorption. Therefore we assumed that the transmission characteristics would be very nearly equivalent from cooker to cooker. A single, average transmission correction value, once determined, could be used throughout the measurements.

A photograph of one of the pressure cookers placed on the turntable in the point source acquisition configuration that we used at the billet assay station set up in Building 321-M is shown in Figure 1. We acquired data for twelve pressure cookers, items 2111 – 2121 and item 2125. The data acquisitions are summarized in Table 1. After the initial background spectrum BKG (acquired on 13 March 2001 in Building 321-M) the next spectrum in Table 1 is the unabsorbed transmission spectrum T_0, which was acquired from a range of 69 inches. The next five spectra, labeled 2111T – 2115T were obtained with pressure cooker items 2111 – 2115 placed successively between the transmission source and the detector. The distance from the pressure cooker item to the detector was 53 inches in each case. We then obtained a long background acquisition BKG313321, which became the background we subtracted from each sample acquisition and the background we used for the determination of our LLD. The next five spectra, labeled 2111 – 2115,

were obtained of those five items with the transmission source removed from the view of the detector.

The transmission factor for each item 2111 – 2115 was then calculated from

$$T_{2111} = \frac{(\text{cps } T_0) - (\text{cps BKG})}{(\text{cps } T_{2111}) - (\text{cps } 2111)} = \frac{6.78 - 0.66}{3.53 - 0.86} = 2.29 \qquad (1)$$

where 6.78 is the detection rate in counts per second (cps) of spectrum T_0, 0.66 is the background rate, 3.53 is the rate of spectrum 2111T, and 0.86 is the rate for spectrum 2111. Clearly, only the denominator of equation (1) changed as we varied each item 2111 – 2115 and 2111T and 2115T.

Table 1. Summary of acquisitions using the 321-M billet assay station.

Spectrum	Count Time (sec)	185 KeV Peak Area	Transmission Factor	Correction Factor
BKG	620.88	569±33		
T_0	102.82	697±29		
2111T	154.84	547±26		
2112T	150	560±26		
2113T	150	531±27		
2114T	150	504±27		
2115T	150	578±28		
2115	300	215±23	1.95	1.40
2114	500	430±35	2.45	1.56
2113	500	404±36	2.24	1.50
2112	500	442±38	2.15	1.47
2111	500	432±37	2.29	1.51
BKG313321	2517	1655±61		
2116	500	398±37	2.73	1.65
2116T	164.2	485±30		
T_{01}	102.2	668±38		
2117	500	412±38		
2118	500	402±37		
2119	500	419±36		
2120	500	365±37		
2121	500	406±38		
2125	6067.4	5633±134		

The transmission factor of 2.29 for item 2111 represents the absorption of the 185 KeV γ-ray from the 4.41-g transmission source. The transmission factors for items 2111 – 2115 are listed in the fourth column of Table 1 and range from 1.95 to 2.45. The assay correction factor is equal to the square root of T, and is listed in the last column of Table 1. We use the square root of T as the absorption correction factor because the γ-rays coming from the sample have to pass through only one pressure cooker wall to reach the detector, while the γ-rays coming from the tranmission source had to pass through both walls. As we predicted, the measured correction factor for each of the first five pressure cookers agreed within a very small range. With one exception, we used the average of these five measured correction factors (1.49±0.06) for all subsequent determinations of HEU content.

For item 2116 we placed the pressure cooker on its side on top of the sample turntable and acquired the sample-only spectrum 2116 and the transmission spectrum 2116T in that attitude. It was not clear which of the two attitudes would yield the smaller correction factor and better acquisition efficiency, so we were interested in obtaining those data from both sample attitudes. The transmission factor from item 2116 was measured from equation (2) to be

$$T_{2116} = \frac{(\text{cps } T_{01}) - (\text{cps BKG})}{(\text{cps } T_{2116}) - (\text{cps } 2116)} = \frac{6.54 - 0.66}{2.95 - 0.80} = 2.73, \qquad (2)$$

where the detection rates come from acquisitions T_{01}, 2116, and 2116T in Table 1. The transmission correction factor of square root(2.73) = 1.65 was used for the assay of item 2116. Since the transmission factor for this on-the-side attitude is significantly larger and out of the range of the five factors measured with the pressure cookers upright, we have used the upright attitude for all subsequent acquisitions.

The calculated contents for each of the twelve pressure cooker items 2111 – 2121 and 2125 were determined with equation (3) and are listed in Table 2.

$$^{235}U = (K_p)(\text{cps})(C_f)(d)^2$$

$$= (2.36 \times 10^{-5})(\text{cps})(C_f)(53 \times 2.54)^2, \qquad (3)$$

where K_p is the point source calibration factor determined for this detection system in units of g-sec/cm^2 in reference 9, Cf is the transmission correction factor described above, and d is the acquisition distance of 53 inches. Column five in Table 2 lists the measured value in units of grams for each item with one sigma uncertainty listed in column six. In column seven we have listed the conservative reported values.[10] These values are each equal to the measured value plus uncertainty listed in column six.

Figure 1. Photograph of a pressure cooker on the 324-M billet assay station turntable.

As a quality control (QC) check on the system, we evaluated the content of the unabsorbed transmission source using the T_0 spectrum acquired at a distance of 69 inches. This evaluation was performed using equation (3) with d = 69 inches, cps = 6.78, and C_f = 1.00. In this QC check we obtain

$$^{235}U = (2.36\text{x}10^{-5})(6.78 - 0.66)(C_f)(69\text{x}2.54)^2 = 4.44 \text{ g},$$

which is in excellent agreement with the known value of 4.41 g.

2.2 Batch Assay Using the Adapted Q^2 Technique

After individual assay of the twelve pressure cooker items above, items 2111 – 2119 were packaged as tightly as possible by FDD personnel into a 55-gallon drum of solid waste. This drum attained the identification number FD2059. We then assayed drum FD2059 using the adapted Q^2 technique described in references 7 and 8. This adapted technique was developed specifically to assay non-uniform, high-density waste for ^{235}U content. We have used it for assay of non-uniform solid waste from 313-M and 321-M and for batch assay of empty 321-M scrap cans.

Table 2. Results of the Individual Far Field Transmission Corrected Assays of Pressure Cooker Items 2111 – 2121 and 2125.

Item Number	Measured cps	s cps	T Correction factor	HEU Content	s HEU Content	Reported Value
2111	0.86	0.07	1.51	0.13	0.05	0.18
2112	0.88	0.08	1.47	0.14	0.05	0.19
2113	0.81	0.07	1.5	0.1	0.05	0.15
2114	0.86	0.08	1.56	0.13	0.05	0.18
2115	0.717	0.077	1.4	< 0.07	< 0.07	< 0.07
2116	0.8	0.07	1.65	0.1	0.05	0.15
2117	0.82	0.08		0.1	0.05	0.15
2118	0.8	0.07		0.09	0.05	0.14
2119	0.84	0.07		0.11	0.04	0.15
2120	0.71	0.07		< 0.07	< 0.07	< 0.07
2125	0.928	0.023		0.17	0.02	0.19

The adapted Q^2 technique uses a 4.41-g source of ^{235}U to approximately convert the Canberra Q^2 assay instrument to a three-segment segmented gamma scanner. This technique of assay of HEU ^{235}U content has the limitations listed below for non-uniform high-density solid waste, but ought to provide a satisfactory assay of uniform low-density waste. In the case of batch assay of scrap cans and batch assay of the pressure cookers, the items were packaged in the identical configuration in every drum. Therefore the batch assay is not seriously disadvantaged by all of the limitations listed immediately below.

2.3 Limitations of the Q^2 method:

- This Q^2 system is optimized for the assay of small, evenly distributed quantities of gamma emitting radionuclides.
- The Q^2 gives the most accurate results when measuring lightly packaged, hydrocarbon-type materials such as paper, plastics, and cardboard.
- An additional uncertainty is introduced because the detectors are not collimated. This allows cross talk between the three vertical segments, making the system effectively a hybrid between a close-field and segmented system. Therefore we have two distinct correction factors for calculating the content.

The data for each of the batch assays of twelve drums containing nine pressure cookers each are listed in Table 3. The format of Table 3 is identical to the format of the tables of references 7 and 8. For each drum we provide the detected γ-ray event rates for the 185 KeV transition from ^{235}U and the transmission correction factors as shown in the Table. For each drum we perform a determination of ^{235}U content in units of nCi/drum using two distinct calculations of the transmission correction factor for each drum segment. One calculation uses the form C_f = square root(T), and one calculation uses the form

$$Cf = \frac{-k \ln \frac{1}{T}}{1 - \left(\frac{1}{T}\right)^k} ,$$

where k is a constant equal to $\pi/4$. The calculation is described completely in reference 7.

Table 3. Q^2 Acquisitions and Results for the twelve drums containing pressure cookers.

Sample	File Name	Count Time	Area	% σ	σ	cps	σ cps	1/T	Cf= SQRT (1/T)	Corr. cps	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)	C_f of ln1/T	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)
T01	T01det1	60	1094	3.08	33.70	18.23	0.56										
T02	T02det1	60	1059	3.13	33.15	17.65	0.55										
T03	T03det1	60	1071	3.14	33.63	17.85	0.56										
FD002061	T12061D1	192.83	1021	3.42	34.92	5.29	0.18	8.98	3.00					2.10			
	T12061D2	192.83	1464	2.88	42.16	7.59	0.22										
	T12061D3	192.83	939	3.69	34.65	4.87	0.18										
	T22061D1	200	1186	3.18	37.71	5.93	0.19										
	T22061D2	200	1424	2.93	41.72	7.12	0.21	8.60	2.93					2.07			
	T22061D2	200	1077	3.44	37.05	5.39	0.19										
	T32061D1	200	932	3.53	32.90	4.66	0.16										
	T32061D2	200	1335	3.04	40.58	6.68	0.20										
	T32061D3	200	1388	3.95	54.83	6.94	0.27	5.32	2.31					1.80			
	2061D1	200.31	661	4.21	27.83	3.30	0.14			9.89				6.92			
	2061D2	200.31	1009	3.43	34.61	5.04	0.17			14.77	32.91	70160	1894	10.44	23.78	50694	1369
	2061D3	200.31	716	4.13	29.57	3.57	0.15			8.25				6.42			
FD002068	T12068D1	600	2952	2	59.04	4.92	0.10	7.18	2.68					1.97			
	T12068D2	600	3724	1.83	68.15	6.21	0.11										
	T12061D3	600	2179	2.45	53.39	3.63	0.09										

Table 3. (Continued)

Sample	File Name	Count Time	Area	% σ	σ	cps	σ cps	1/T	Cf= SQRT (1/T)	Corr. cps	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)	C_f of ln1/T	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)
	T22068D1	200	819	3.88	31.78	4.10	0.16										
	T22068D2	200	1173	3.25	38.12	5.87	0.19	8.53	2.92					2.07			
	T22068D3	200	923	3.73	34.43	4.62	0.17										
	T32068D1	200	719	4.07	29.26	3.60	0.15										
	T32068D2	200	1204	3.25	39.13	6.02	0.20										
	T32068D3	200	1225	3.23	39.57	6.13	0.20	5.16	2.27					1.78			
	2068D1	200	485	5.01	24.30	2.43	0.12			6.50				4.77			
	2068D2	200	753	4.06	30.57	3.77	0.15			11.00	23.52	50160	1354	7.78	17.27	36825	994
	2068D3	200	531	4.86	25.81	2.66	0.13			6.03				4.72			
FD002049	T12049D1	200	1546	2.71	41.90	7.73	0.21	3.38	1.84					1.55			
	T12049D2	200	1188	3.24	38.49	5.94	0.19										
	T12049D3	200	793	4.4	34.89	3.97	0.17										
	T22049D1	200	849	3.8	32.26	4.25	0.16										
	T22049D2	200	1348	3.04	40.98	6.74	0.20	6.19	2.49					1.88			
	T22049D3	200	884	3.84	33.95	4.42	0.17										
	T32049D1	200	695	4.21	29.26	3.48	0.15										
	T32049D2	200	1373	3	41.19	6.87	0.21										
	T32049D3	200	1085	3.43	37.22	5.43	0.19	7.37	2.71					1.98			
	2049D1	200	487	5.14	25.03	2.44	0.13			4.48				3.78			
	2049D2	200	769	4.07	31.30	3.85	0.16			9.56	22.17	47278	1277	7.23	16.95	36131	976
	2049D3	200	599	4.49	26.90	3.00	0.13			8.13				5.93			

Table 3. (Continued)

Sample	File Name	Count Time	Area	% σ	σ	cps	σ cps	1/T	Cf= SQRT (1/T)	Corr. cps	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)	C_f of ln1/T	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)
T01	T01det1	60	952	3.32	31.61	15.87	0.53										
T02	T02det1	60	907	3.42	31.02	15.12	0.52										
T03	T03det1	60	987	3.34	32.97	16.45	0.55										
FD002057	T12057D1	140	1205	3.11	37.48	8.61	0.27	2.38	1.54					1.38			
	T12057D2	140	1185	3.21	38.04	8.46	0.27										
	T12057D3	140	847	3.97	33.63	6.05	0.24										
	T22057D1	140	585	4.43	25.92	4.18	0.19										
	T22057D2	140	720	4.26	30.67	5.14	0.22	11.09	3.33					2.23			
	T22057D3	140	754	4.05	30.54	5.39	0.22										
	T32057D1	140	375	5.99	22.46	2.68	0.16										
	T32057D2	140	759	4.07	30.89	5.42	0.22										
	T32057D3	140	975	3.52	34.32	6.96	0.25	4.63	2.15					1.72			
	2057D1	328.97	642	4.39	28.18	1.95	0.09			3.01				2.69			
	2057D2	328.97	1223	3.2	39.14	3.72	0.12			12.38	23.03	49108	1326	8.27	17.07	36392	983
	2057D3	328.97	1168	3.28	38.31	3.55	0.12			7.64				6.11			
FD002063	T12063D1	140	712	4.09	29.12	5.09	0.21	10.20	3.19					2.17			
	T12063D2	140	95	3.59	3.41	0.68	0.02										
	T12063D3	140	671	4.45	29.86	4.79	0.21										

Table 3. (Continued)

Sample	File Name	Count Time	Area	% σ	σ	cps	σ cps	1/T	Cf= SQRT (1/T)	Corr. cps	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)	C_f of ln1/T	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)
	T22063D1	140	763	3.97	30.29	5.45	0.22										
	T22063D2	140	1051	3.43	36.05	7.51	0.26	5.65	2.38					1.83			
	T22063D3	140	700	4.4	30.80	5.00	0.22										
	T32063D1	140	721	4	28.84	5.15	0.21										
	T32063D2	140	884	3.87	34.21	6.31	0.24										
	T32063D3	140	1069	3.35	35.81	7.64	0.26	4.01	2.00					1.64			
	2063D1	200	707	4.29	30.33	3.54	0.15			11.29				7.69			
	2063D2	200	942	3.71	34.95	4.71	0.17			11.20	29.87	63694	1720	8.62	22.36	47676	1287
	2063D3	200	738	4.01	29.59	3.69	0.15			7.39				6.06			
FD002058	T12058D1	140	818	3.87	31.66	5.84	0.23	6.47	2.54					1.91			
	T12058D2	140	1010	3.48	35.15	7.21	0.25										
	T12058D3	140	680	4.23	28.76	4.86	0.21										
	T22058D1	140	763	4.13	31.51	5.45	0.23										
	T22058D2	140	970	3.54	34.34	6.93	0.25	7.31	2.70					1.98			
	T22058D3	140	737	4.03	29.70	5.26	0.21										
	T32058D1	140	642	4.44	28.50	4.59	0.20										
	T32058D2	140	869	3.83	33.28	6.21	0.24										
	T32058D3	140	941	3.55	33.41	6.72	0.24	5.55	2.36					1.82			
	2058D1	200	680	4.47	30.40	3.40	0.15			8.65				6.48			
	2058D2	200	953	3.6	34.31	4.77	0.17			12.88	30.66	65382	1765	9.42	22.95	48928	1321
	2058D3	200	775	3.91	30.30	3.88	0.15			9.13				7.05			

Table 3. (Continued)

Sample	File Name	Count Time	Area	% σ	σ	cps	σ cps	1/T	Cf= SQRT (1/T)	Corr. cps	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)	C_f of ln1/T	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)
FD002060	T12060D1	140	870	3.81	33.15	6.21	0.24	4.69	2.17					1.73			
	T12060D2	140	992	3.49	34.62	7.09	0.25										
	T12060D3	140	526	4.78	25.14	3.76	0.18										
	T22060D1	140	717	4.31	30.90	5.12	0.22										
	T22060D2	140	863	3.83	33.05	6.16	0.24	7.37	2.72					1.98			
	T22060D3	140	628	4.32	27.13	4.49	0.19										
	T32060D1	140	537	5.03	27.01	3.84	0.19										
	T32060D2	140	875	3.75	32.81	6.25	0.23										
	T32060D3	140	969	3.46	33.53	6.92	0.24	3.97	1.99					1.64			
	2060D1	200	569	4.82	27.43	2.85	0.14			6.16				4.91			
	2060D2	200	804	4.03	32.40	4.02	0.16			10.92	22.94	48908	1321	7.96	17.69	37718	1018
	2060D3	200	588	4.42	25.99	2.94	0.13			5.86				4.81			
T01	T01det1	60	1077	3.32	35.76	17.95	0.60										
T02	T02det1	60	967	3.42	33.07	16.12	0.55										
T03	T03det1	60	1007	3.34	33.63	16.78	0.56										

Table 3. (Continued)

Sample	File Name	Count Time	Area	% σ	σ	cps	σ cps	1/T	Cf= SQRT (1/T)	Corr. cps	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)	C_f of ln1/T	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)
FD002064	T12064D1	140	617	4.79	29.55	4.41	0.21	15.88	3.99					2.45			
	T12064D2	140	948	3.65	34.60	6.77	0.25										
	T12064D3	140	484	5.1	24.68	3.46	0.18										
	T22064D1	140	554	5.17	28.64	3.96	0.20										
	T22064D2	140	780	4.04	31.51	5.57	0.23	12.64	3.55					2.31			
	T22064D3	140	570	4.88	27.82	4.07	0.20										
	T32064D1	140	635	4.42	28.07	4.54	0.20										
	T32064D2	140	1052	3.4	35.77	7.51	0.26										
	T32064D3	140	737	4.08	30.07	5.26	0.21	6.37	2.52					1.90			
	2064D1	200	668	4.56	30.46	3.34	0.15			13.31				8.18			
	2064D2	200	846	3.92	33.16	4.23	0.17			15.04	34.92	74466	2011	9.75	22.88	48787	1317
	2064D3	200	521	4.82	25.11	2.61	0.13			6.58				4.94			
FD002029	T12029D1	140	1246	3.14	39.12	8.90	0.28	2.61	1.62					1.42			
	T12029D2	140	901	3.69	33.25	6.44	0.24										
	T12029D3	140	585	4.64	27.14	4.18	0.19										
	T22029D1	140	596	4.77	28.43	4.26	0.20										
	T22029D2	140	1075	3.36	36.12	7.68	0.26	4.40	2.10					1.69			
	T22029D3	140	655	4.3	28.17	4.68	0.20										
	T32029D1	140	541	4.75	25.70	3.86	0.18										
	T32029D2	140	880	3.77	33.18	6.29	0.24										
	T32029D3	140	1015	3.36	34.10	7.25	0.24	4.06	2.01					1.65			

Table 3. (Continued)

Sample	File Name	Count Time	Area	% σ	σ	cps	σ cps	1/T	Cf= SQRT (1/T)	Corr. cps	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)	C_f of ln1/T	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)
	2029D1	200	481	5.49	26.41	2.41	0.13			3.89				3.42			
	2029D2	200	766	4.09	31.33	3.83	0.16			8.04	18.10	38603	1042	6.48	14.96	31907	861
	2029D3	200	614	4.41	27.08	3.07	0.14			6.18				5.06			
FD002013	T12013D1	140	837	3.96	33.15	5.98	0.24	4.90	2.21					1.75			
	T12013D2	140	864	3.78	32.66	6.17	0.23										
	T12013D3	140	589	4.53	26.68	4.21	0.19										
	T22013D1	140	606	4.78	28.97	4.33	0.21										
	T22013D2	140	844	3.78	31.90	6.03	0.23	12.08	3.48					2.28			
	T22013D3	140	589	4.53	26.68	4.21	0.19										
	T32013D1	140	439	5.59	24.54	3.14	0.18										
	T32013D2	140	869	3.75	32.59	6.21	0.23										
	T32013D3	140	886	3.71	32.87	6.33	0.23	5.90	2.43					1.85			
	2013D1	200	504	5.39	27.17	2.52	0.14			5.58				4.41			
	2013D2	200	925	3.61	33.39	4.63	0.17			16.07	30.04	64056	1730	10.54	21.35	45521	1229
	2013D3	200	691	4.12	28.47	3.46	0.14			8.39				6.40			
FD002081	T12081D1	140	763	4.15	31.66	5.45	0.23	7.42	2.72					1.98			
	T12013D2	140	979	3.52	34.46	6.99	0.25										
	T12081D3	140	623	4.38	27.29	4.45	0.19										
	T22081D1	140	816	4.02	32.80	5.83	0.23										
	T22081D2	140	951	3.59	34.14	6.79	0.24	7.38	2.72					1.98			
	T22081D3	140	576	4.65	26.78	4.11	0.19										

Table 3. (Continued)

Sample	File Name	Count Time	Area	% σ	σ	cps	σ cps	1/T	Cf= SQRT (1/T)	Corr. cps	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)	C_f of ln1/T	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)
	T32081D1	140	645	4.56	29.41	4.61	0.21										
	T32081D2	140	803	4.02	32.28	5.74	0.23										
	T32081D3	140	825	3.82	31.52	5.89	0.23	5.34	2.31					1.80			
	2081D1	200	633	4.59	29.05	3.17	0.15			8.62				6.28			
	2081D2	200	899	3.63	32.63	4.50	0.16			12.21	27.12	57815	1561	8.91	20.08	42811	1156
	2081D3	200	544	4.86	26.44	2.72	0.13			6.29				4.89			
FD002062	T12062D1	140	731	4.39	32.09	5.22	0.23	7.90	2.81					2.02			
	T12062D2	140	927	3.67	34.02	6.62	0.24										
	T12062D3	140	599	4.52	27.07	4.28	0.19										
	T22062D1	140	667	4.47	29.81	4.76	0.21										
	T22062D2	140	877	3.78	33.15	6.26	0.24	8.88	2.98					2.09			
	T22062D3	140	729	4.08	29.74	5.21	0.21										
	T32062D1	140	532	5.09	27.08	3.80	0.19										
	T32062D2	140	851	3.85	32.76	6.08	0.23										
	T32062D3	140	919	3.6	33.08	6.56	0.24	5.26	2.29					1.79			
	2062D1	200	615	4.65	28.60	3.08	0.14			8.64				6.22			
	2062D2	200	871	3.84	33.45	4.36	0.17			12.98	29.28	62420	1685	9.10	21.30	45406	1226
	2062D3	200	668	4.19	27.99	3.34	0.14			7.66				5.98			
FD002059	T12059D1	140	806	3.98	32.08	5.76	0.23	6.56	2.56					1.91			
	T12059D2	140	1109	3.34	37.04	7.92	0.26										
	T12059D3	140	624	4.41	27.52	4.46	0.20										

Table 3. (Continued)

Sample	File Name	Count Time	Area	% σ	σ	cps	σ cps	1/T	Cf= SQRT (1/T)	Corr. cps	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)	C_f of ln1/T	Corr. Sum (cps)	Drum Activity (dps)	Drum Activity (nCi)
	T22059D1	140	735	4.23	31.09	5.25	0.22										
	T22059D2	140	947	3.59	34.00	6.76	0.24	8.88	2.98					2.09			
	T22059D3	140	699	4.17	29.15	4.99	0.21										
	T32059D1	140	585	4.76	27.85	4.18	0.20										
	T32059D2	140	951	3.62	34.43	6.79	0.25										
	T32059D3	140	975	3.56	34.71	6.96	0.25	4.46	2.11					1.70			
	2059D1	200	635	4.52	28.70	3.18	0.14			8.13				6.08			
	2059D2	200	971	3.56	34.57	4.86	0.17			14.47	29.29	62442	1686	10.15	21.61	46067	1244
	2059D3	200	633	4.45	28.17	3.17	0.14			6.69				5.38			

3. RESULTS AND DISCUSSION

The results for each drum are summarized in Table 4. Columns two and three in Table 4 list the measured content and uncertainty for each drum in units of nCi/drum. Columns four and five list the results and uncertainty in units of g/drum. Columns six and seven list the results for each drum from the direct Q^2 analysis of the data. The last column lists the recommended value to report. Note that the direct Q^2 results are always about 25% lower than the results from the adapted technique and are generally not in good agreement within the statistical uncertainties of the two methods.

We were very interested in comparing the Q^2 results for drum FD2059 with the sum of the individual assays for pressure cookers 2111 – 2119 that were packaged in FD2059. From Table 2 we obtain a sum of (0.94±0.14) g of ^{235}U in those nine items. For this sum we used a value of (0.035±0.035) g for item 2115 that was reported as < 0.07 g. From Table 4 we note that the adapted Q^2 technique of assay yielded a content of (0.76±0.21) g, and the direct Q^2 technique of assay yielded a content of (0.59±0.02) g. The results from the adapted technique are in good agreement with the sum of the individual assays.

Even though each 55-gallon drum was packed identically with nine pressure cookers, each drum represents an inhomogeneous distribution of mass. The fairly light masses of about 60 kg yield direct Q^2 transmission corrections of near 1.8 for each drum. The Q^2 instrument assumes that the drum is 100% full with low-density homogeneous material. Looking at our segmented transmission corrections in Table 3, we observe that the transmission corrections are quite constant throughout, with very little dependence on segment. This segment independence is in contrast to the adapted Q^2 measurements obtained on the scrap cans of reference 8 and the high-density waste of reference 7.

The uniform transmission values result from the uniform packing. Each drum was packed exactly in the same arrangement of nine pressure cookers. We note that if we use only the square root(1/T) correction factor in the spreadsheet of Table 3, the agreement of the batch assay of drum FD2059 with the individual assay improves from (0.76±0.15) to (0.88±0.03) g. Since the individual assays used the square root(1/T) correction factor, the improved agreement is an excellent indicator that the adapted Q^2 method of assay is reliable for these twelve drums.

Table 4. Results of the Q^2 assays of the thirteen drums filled with 321-M pressure cookers.

Drum Number	Adaptd Q^2 Results (nCi/drum)	s Adaptd Q^2 Results (nCi/drum)	Adaptd Q^2 Results (g/drum)	s Adaptd Q^2 Results (g/drum)	Direct Q^2 Results (g/drum)	s direct Q^2 Results (g/drum)	Reported Value (g/drum)
FD2059	1460	310	0.76	0.15	0.59	0.02	**0.91**
FD2061	1630	370	0.85	0.19	0.62	0.02	**1.04**
FD2062	1460	320	0.76	0.17	0.58	0.02	**0.93**
FD2049	1630	370	0.85	0.19	0.47	0.01	**1.04**
FD2081	1360	290	0.71	0.15	0.57	0.02	**0.86**
FD2013	1480	350	0.77	0.18	0.54	0.02	**0.95**
FD2058	1543	314	0.8	0.16	0.65	0.02	**0.96**
FD2057	1154	243	0.6	0.13	0.47	0.01	**0.73**
FD2064	1660	370	0.87	0.26	0.56	0.02	**1.13**
FD2068	1170	250	0.61	0.13	0.47	0.01	**0.74**
FD2029	950	130	0.5	0.07	0.44	0.01	**0.57**
FD2063	1504	306	0.78	0.16			**0.94**

4. CONCLUSION

We have used the adapted procedure of WSRC-TR-2001-00004 to transform the 313-M Q^2 assay instrument to a three-segment segmented gamma scanner in order to assay the ^{235}U HEU content of twelve 55-gallon drums filled with nine 321-M process pressure cookers each. The pressure cookers contained residual HEU only, but were contaminated with process material from 25 years of use. Using our batch technique of assay, the twelve drums were reported to have HEU residue contents ranging from 0.50±0.07 g to 0.87±0.26 g. The drums were observed to have nearly constant transmission characteristics for each of the 36 segments of the twelve drums assayed. This consistency is a characteristic of the uniform packaging that was employed for each drum, and we believe lends significant support to the credibility of the measurements.

The measured values for one drum were compared to the values obtained for one batch of nine pressure cookers that were assayed individually on the 324-M far-field transmission corrected γ-PHA assay station. This station was assembled specifically for the purpose of assaying individual items with geometry and density similar to the pressure cookers. The comparison demonstrated that the adapted technique yielded results that are in very good agreement with the individual assay results.

5. ACKNOWLEDGEMENTS

The authors would like to extend their sincere thanks to Henry Burruss for scheduling and providing the operations support that made it possible for us to conduct this work.

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